

# **AN OVERVIEW OF THE NASA FUNDAMENTAL AERONAUTICS PROGRAM SUBSONIC FIXED WING PROJECT AND ULTRA HIGH BYPASS PARTNERSHIP RESEARCH GOALS**

Christopher E. Hughes  
NASA Glenn Research Center  
Cleveland, Ohio 44135

## **Abstract**

An overview of the NASA Fundamental Aeronautics Program (FAP) mission and goals is presented. One of the subprograms under the FAP, the Subsonic Fixed Wing Project (SFW), is the focus of the presentation. The SFW system environmental metrics are discussed, along with highlights of planned, systematic approach to research to reduce the environmental impact of commercial aircraft in the areas of acoustics, fuel burn and emissions. The presentation then focuses on collaborative research being conducted with U.S. Industry on the Ultra High Bypass (UHB) engine cycle, the propulsion cycle selected by the SFW to meet the system goals. The partnerships with General Electric Aviation to investigate Open Rotor propulsion concepts and with Pratt & Whitney to investigate the Geared Turbofan UHB engine are highlighted, including current and planned future collaborative research activities with NASA and each organization.



# **An Overview of the NASA Fundamental Aeronautics Program Subsonic Fixed Wing Project and Ultra High Bypass Partnership Research Goals**

*Chris Hughes*

*Manager, Ultra High Bypass Partnership Element*

15th AIAA/CEAS Aeroacoustics Conference  
(30th AIAA Aeroacoustics Conference)  
11-13 May 2009  
Miami, Florida



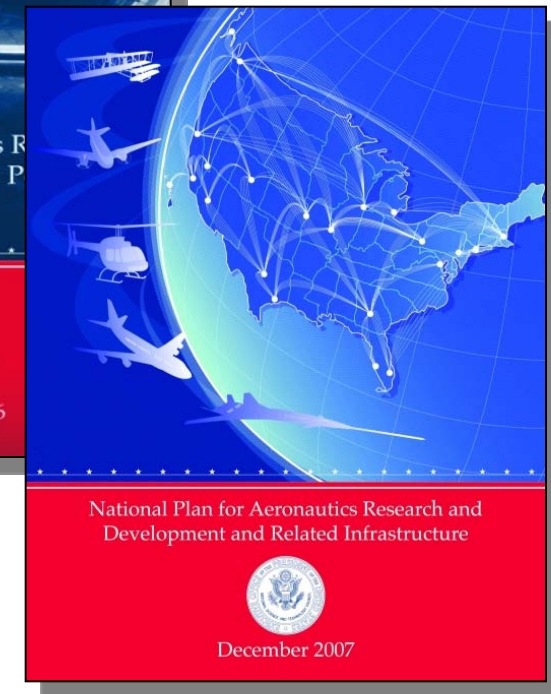
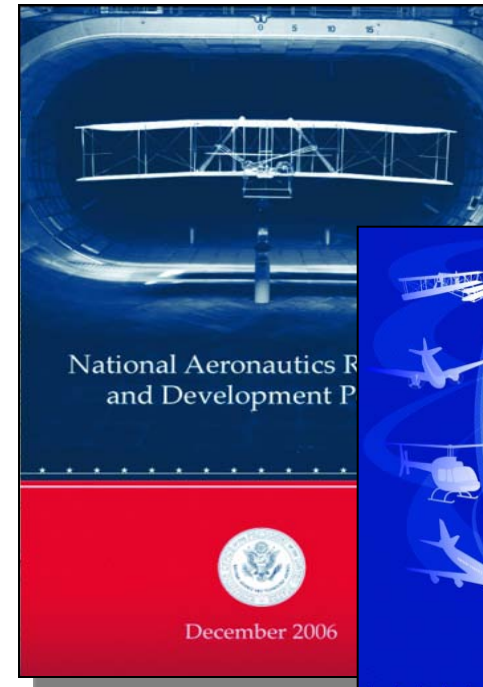
# National Aeronautics R&D Policy and Plan

## • Policy

- Executive Order signed December 2006
- Outlines 7 basic principles to follow in order for the U.S. to “maintain its technological leadership across the aeronautics enterprise”
- **Mobility**, national security, aviation safety, security, workforce, **energy & efficiency**, and **environment**

## • Plan (including Related Infrastructure)

- Plan signed by Pres. Bush December 2007
- Goals and Objectives for all basic principles (except Workforce, being worked under a separate doc)
- Summary of **challenges in each area** and the facilities needed to support related R&D
- **Specific quantitative targets** where appropriate
- More detailed document/version to follow later in 2008



*Executive Order, Policy, Plan, and Goals & Objectives all available on the web*

*For more information visit: [http://www.ostp.gov/cs/nstc/documents\\_reports](http://www.ostp.gov/cs/nstc/documents_reports)*



# Subsonic Fixed Wing Project

.... technology for dramatically improving noise, emissions, & performance

- ***Objectives***

- (1a) Development of prediction and analysis tools for reduced uncertainty in design process

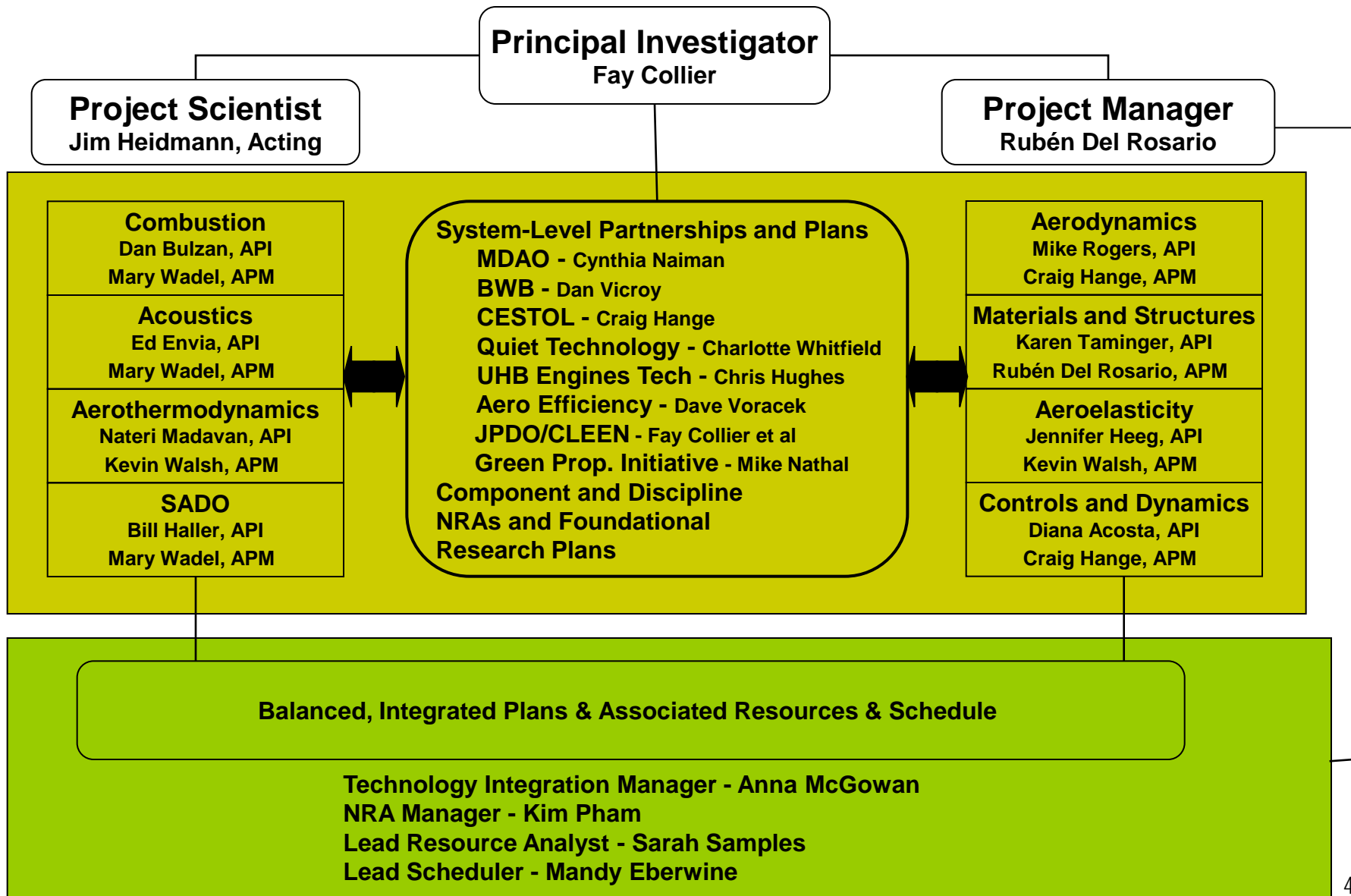
- (1b) Development of concepts/technologies for enabling dramatic improvements in noise, emissions and performance characteristics of subsonic/transonic aircraft

- ***Relevance***

- Direct impact on future designs of a wide range of subsonic aircraft relevant to industry, DoD, and OGA
  - Direct impact on JPDO & NextGen operational and environmental goals and objectives



# Organization of SFW Project





# System Level Metrics

.... technology for dramatically improving noise, emissions, & performance

CORNERS OF THE TRADE SPACE	N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90)	N+3 (2030-2035 EIS) Generation Advanced Aircraft Concepts (relative to user defined reference)
Noise	- 32 dB (cum below Stage 4)	- 42 dB (cum below Stage 4)	- 71 dB (cum below Stage 4)
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-40%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

\*\* An additional reduction of 10 percent may be possible through improved operational capability

\* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

--- EIS = Entry Into Service; IOC = Initial Operating Capability



N+1



N+2



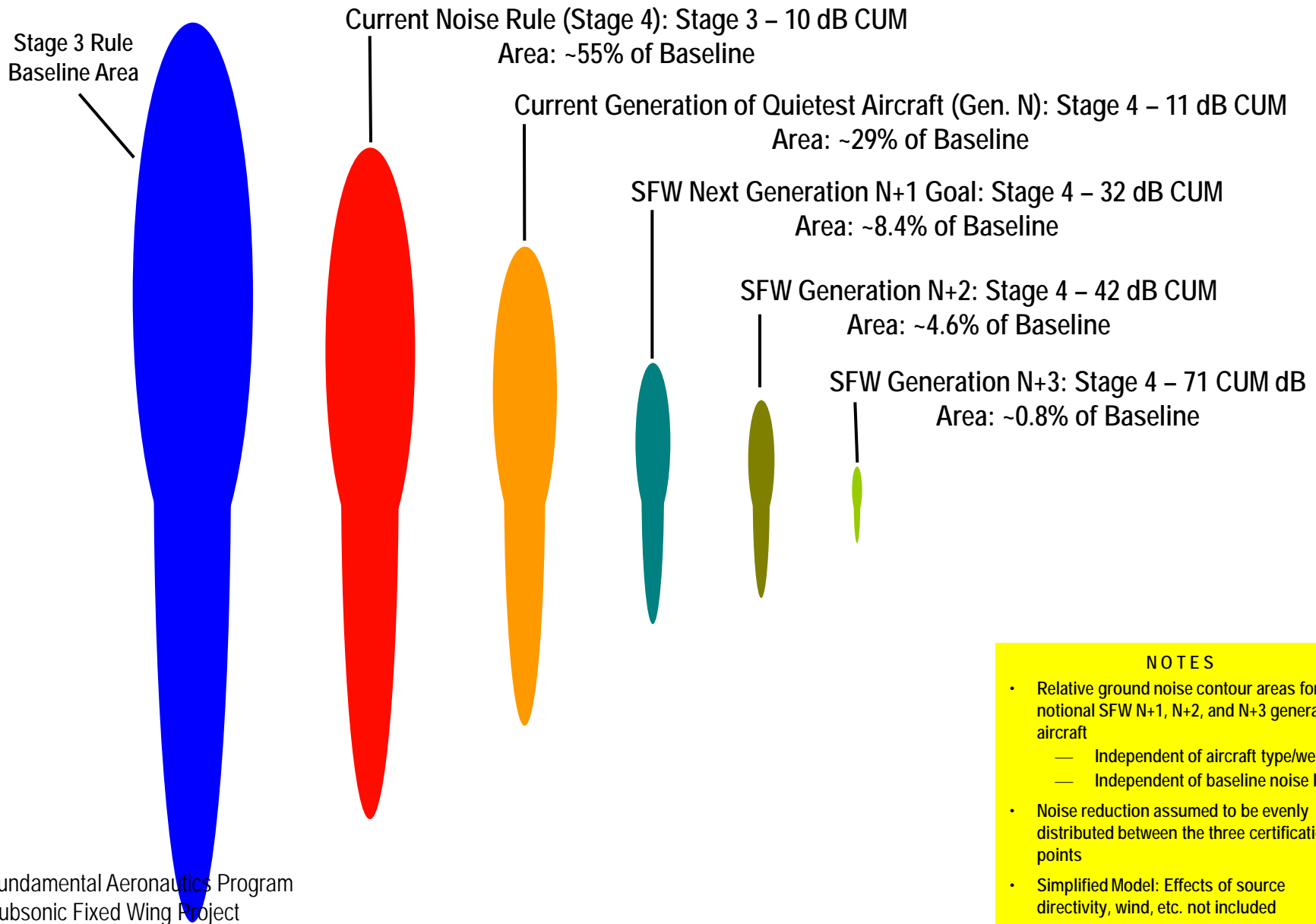
N+3

## Approach

- Enable Major Changes in Engine Cycle/Airframe Configurations
- Reduce Uncertainty in Multi-Disciplinary Design and Analysis Tools and Processes
- Develop/Test/ Analyze Advanced Multi-Discipline Based Concepts and Technologies
- Conduct Discipline-based Foundational Research



# Change in noise “footprint” area based on SFW goals for single landing and takeoff



## NOTES

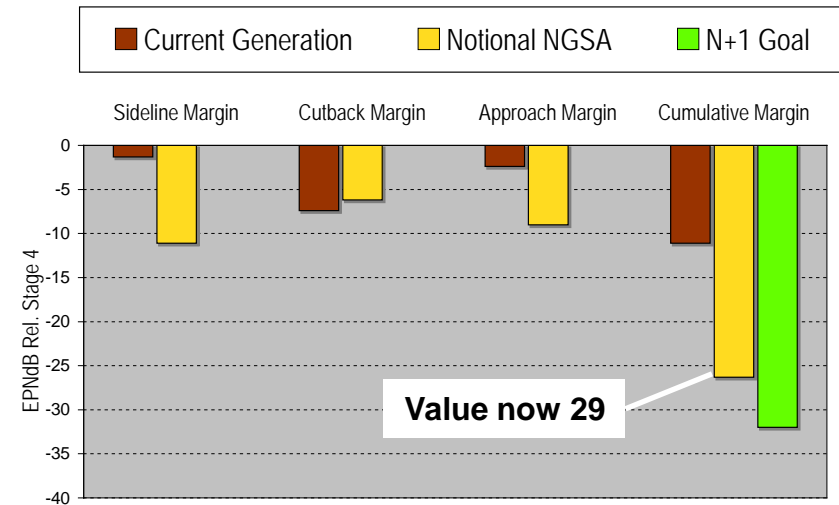
- Relative ground noise contour areas for notional SFW N+1, N+2, and N+3 generation aircraft
  - Independent of aircraft type/weight
  - Independent of baseline noise level
- Noise reduction assumed to be evenly distributed between the three certification points
- Simplified Model: Effects of source directivity, wind, etc. not included



# Noise Reduction

## “N + 1” Conventional Small Twin

- 32 EPNdB cumulative below Stage 4
- Target Next Generation Single Aisle (NGSA)
- Ultra-High Bypass (UHB) engines
- Noise Reduction (NR) technologies for fans, landing gear, propulsion airframe aeroacoustics
- Light weight acoustic treatment in multi-functional structures



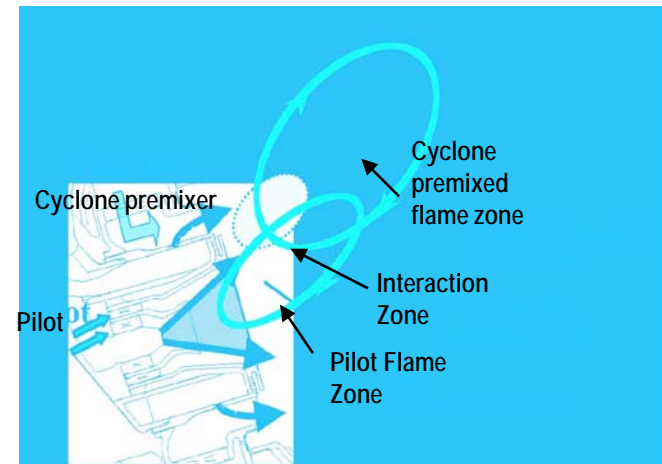




# LTO NO<sub>x</sub> Emissions Reduction

## Conventional Small Twin: N+1

- 60% LTO NO<sub>x</sub> reduction below CAEP6
- Target Next Generation Single Aisle (NGSA)
- Annular combustor TAPS (GE)
  - Improved fuel/air mixers
- TALONX (P&W)
  - Optimized quench section for improved mixing
  - Improved fuel/air mixing in rich zone



Cyclone Main with Pilot Concept

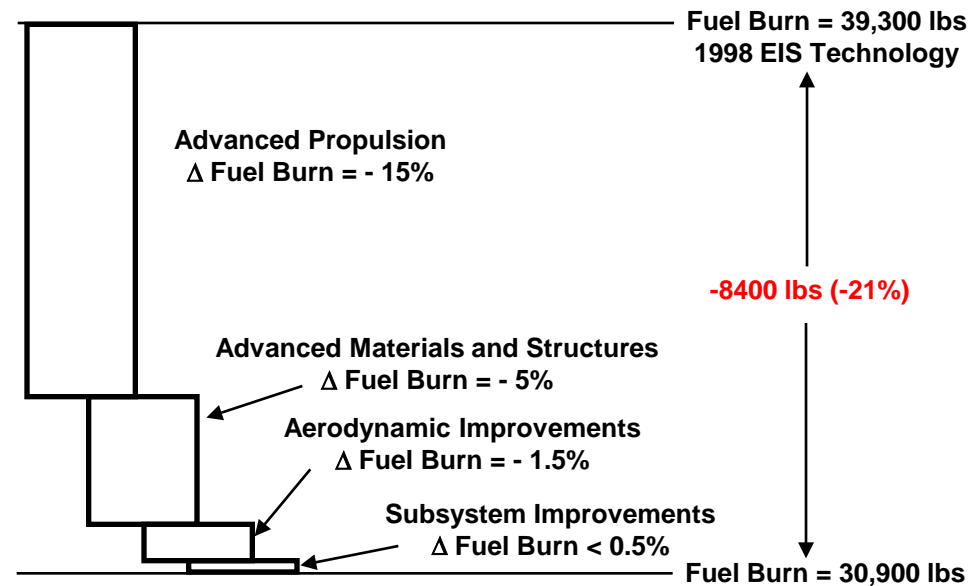


# Performance - Fuel Burn

## Detailed System Analysis

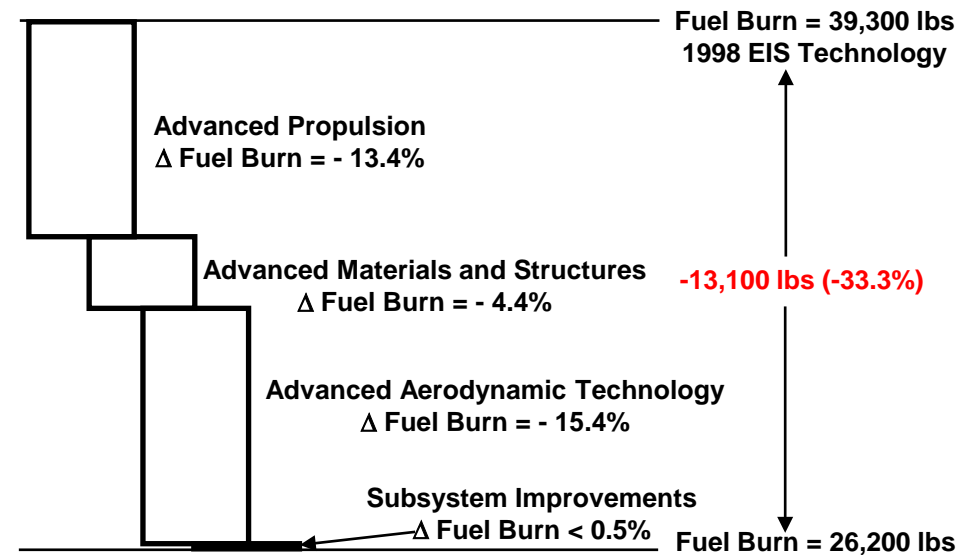
### "N + 1" Conventional Small Twin

- 162 pax, 2940 nm mission baseline
- Ultra high bypass ratio engines, geared
- Key technology targets:
  - +1 point increase in turbomachinery efficiencies
  - 25% reduction in turbine cooling flow enabled by: improved cooling effectiveness and advanced materials
  - +50 deg. F compressor temps (T3)
  - +100 deg. F turbine rotor inlet temps
  - -15% airframe structure weight
  - -1% total vehicle drag
  - -15% hydraulic system weight



### "N + 1" Advanced Small Twin

- All technologies listed above plus:
    - Hybrid Laminar Flow Control
    - 67% upper wing,
    - 50% lower wing,
    - tail, nacelle
- Result = -17% total vehicle drag**





## SFW Ultra High Bypass Partnership Research

### ➤ *Objective*

- Develop noise reduction, emission reduction and performance improvement technologies for the Ultra High Bypass engine cycle, then demonstrate and validate their potential in full scale applications

### ➤ *Meeting SFW Goals Requires Evaluating Game-Changing Architectures*

***NASA has a strong and successful history of developing aircraft propulsion improvement technologies with Industry/OGA/Academia partners***



## ➤ *Technology Challenges*

- **Geared Turbofan (P&W)**

- Small, high density engine core – required to achieve higher fan bypass ratio without significantly increasing fan diameter
- Aerodynamic performance – larger fan diameter means larger nacelle and higher drag
- Installation – increasingly larger diameter engines means limited application for current, low wing aircraft designs

- **Open Rotor (GE)**

- Noise – rotor blade noise radiates unobstructed to the environment, well above current aircraft noise regulation limits
- Installation – very large blade diameters mean significant aircraft installation problems, perhaps requiring all new aircraft design
- Power – slow, counter-rotating rotors requires novel turbine power distribution designs to optimize turbomachinery efficiency



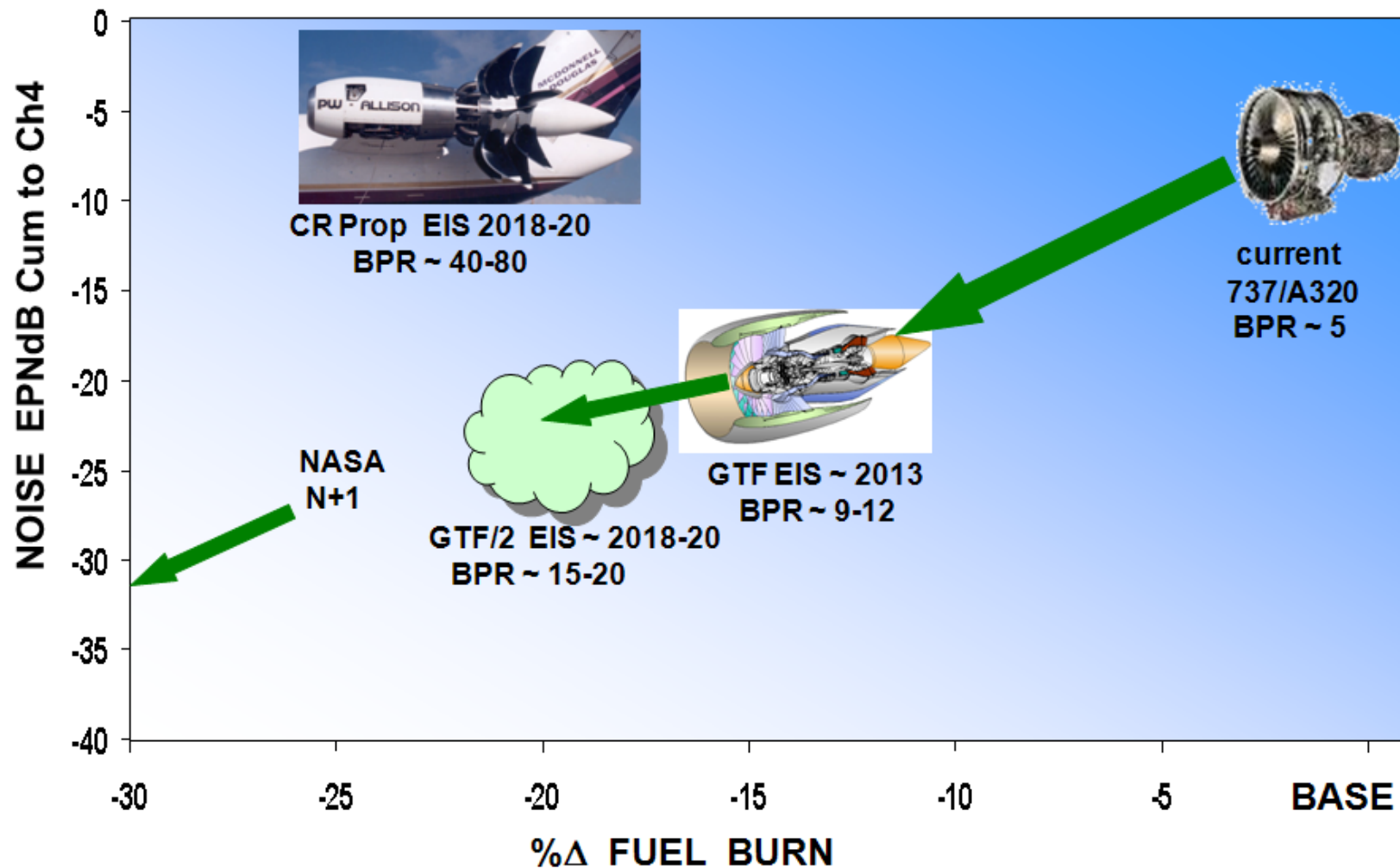
## NASA / P&W UHB Partnership Research





# NASA / P&W UHB Partnership Research

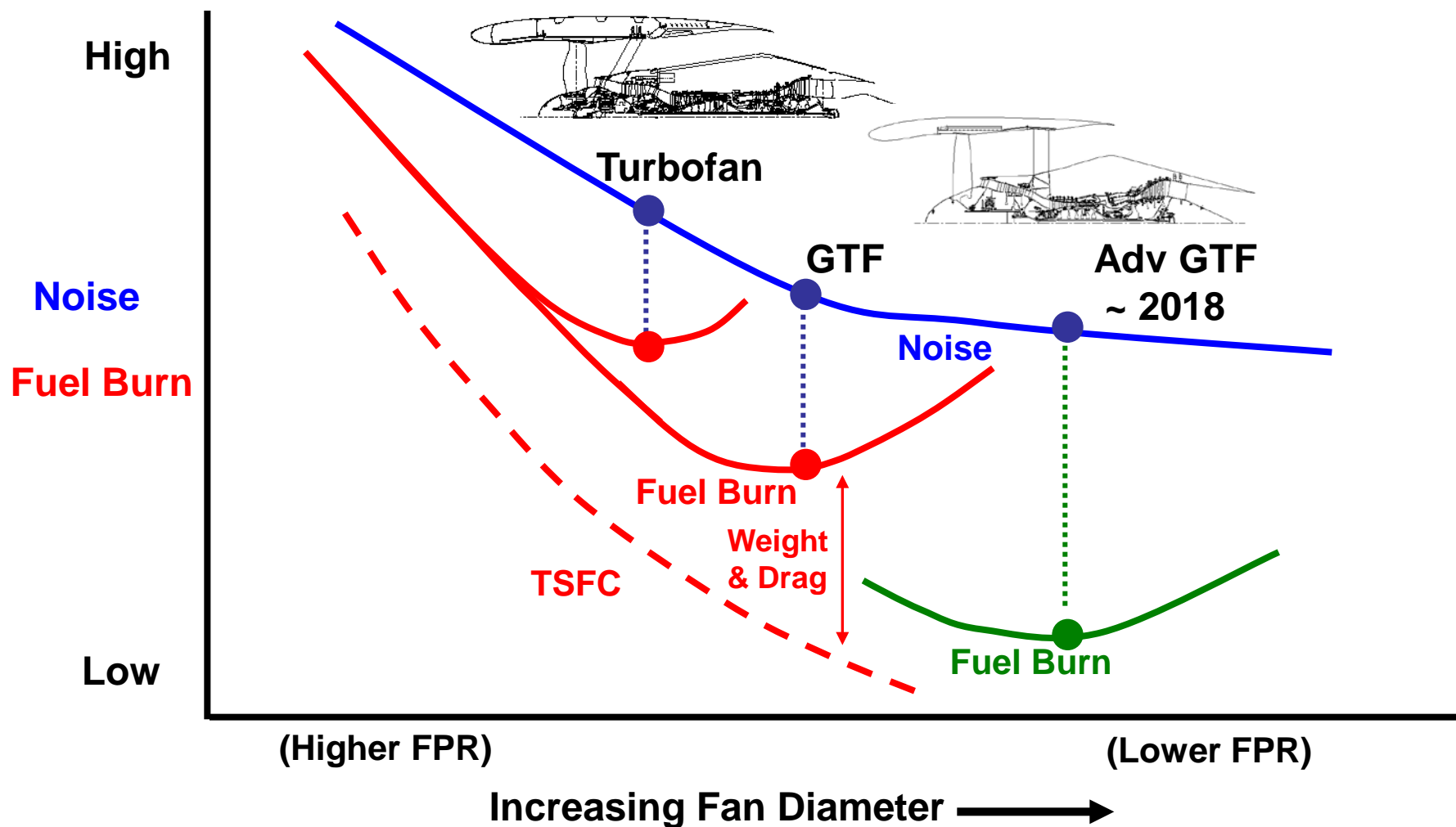
## ➤ Meeting SFW Goals Requires Evaluating Game-Changing Architectures





# NASA / P&W UHB Partnership Research

➤ *Meeting SFW Goals Requires Evaluating Game-Changing Architectures*

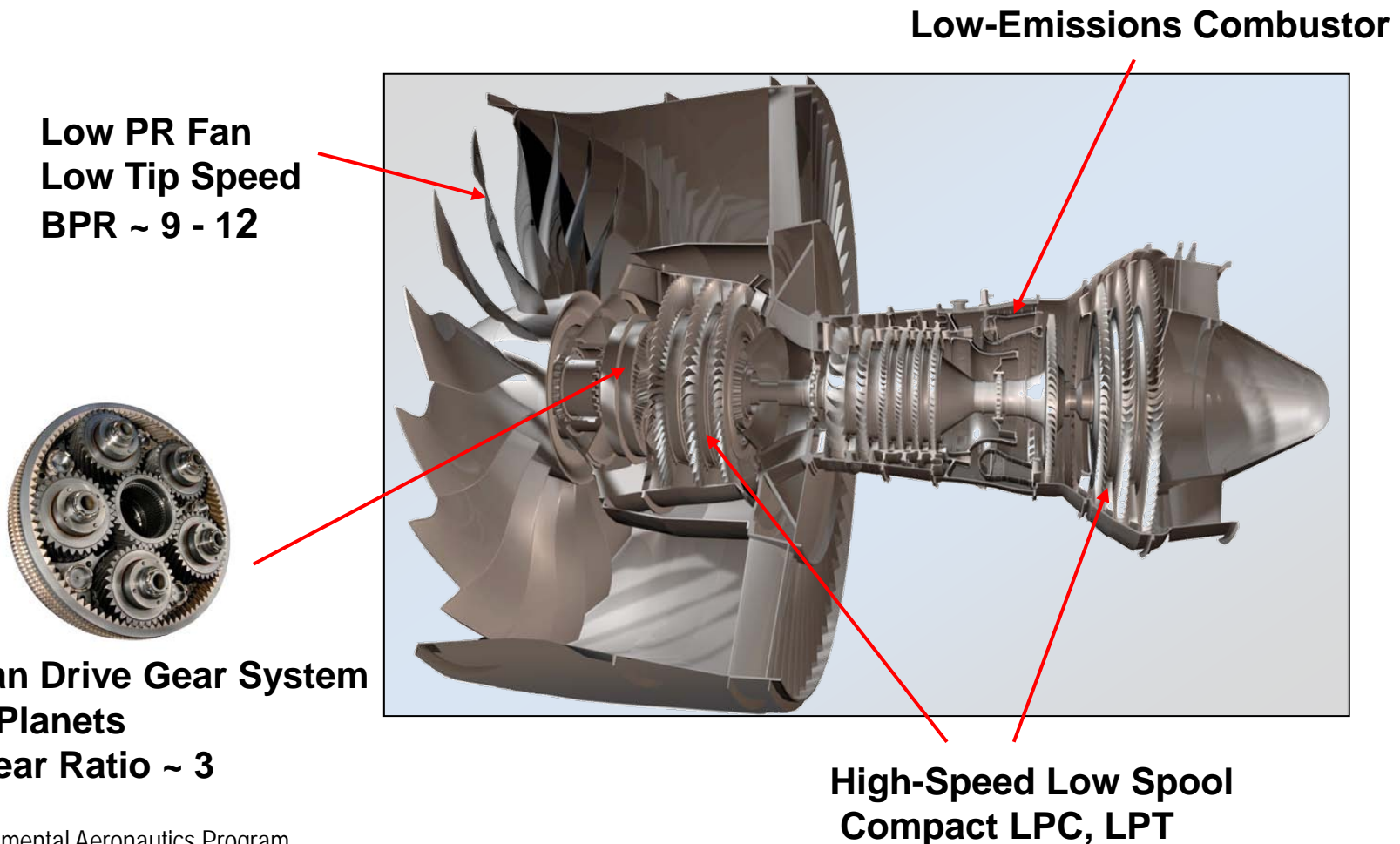






# NASA / P&W UHB Partnership Research

## NASA Partnership Areas on Pratt & Whitney Geared TurboFan (GTF™)







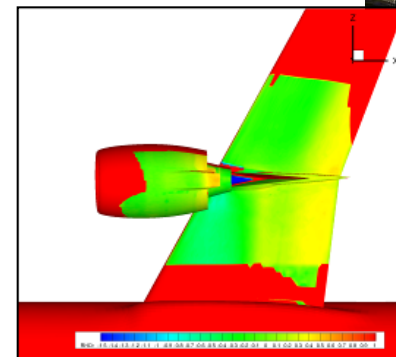
# NASA / P&W UHB Partnership Research

## ➤ *Pratt & Whitney Geared Turbofan*

- 22" Subscale Rig Test
  - Successful demonstration of UHB fan technology
  - Fan efficiency exceeded expectations
  - Overall advantage of low PR, low tip speed fan demonstrated
  - Test data used to define fan aerodynamics for full scale demonstrator engine
- Nacelle/Wing Interaction Test
  - Highly successful collaboration between Industry Partner and three NASA centers
  - Test data provided design confidence for nacelle-wing integration at BPR = 12



*22" GTF fan model in Glenn 9'x15' wind tunnel*



*Pressure Sensitive Paint results*



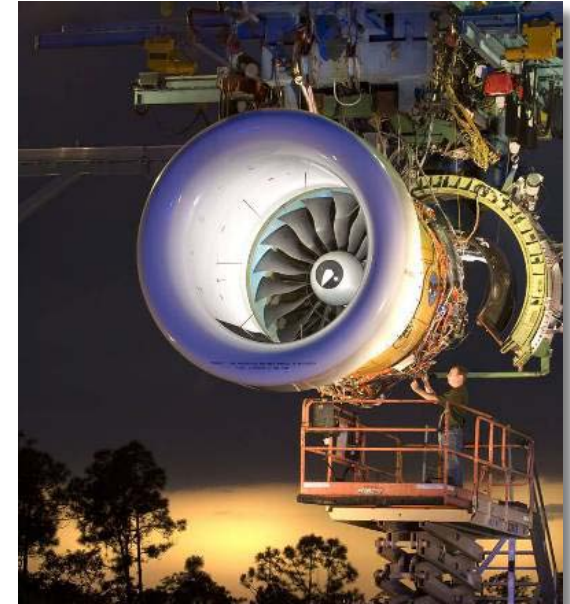
*Powered half-span model test in Ames 11' wind tunnel*



# NASA / P&W UHB Partnership Research

## ➤ *Pratt & Whitney Geared Turbofan*

- Geared Turbofan Demonstrator Engine
  - Successful ground demonstration of Geared Turbofan concept completed May 2008
    - Predicted fan performance verified
    - Acoustic characteristics within expectations
- Future Collaboration
  - Space Act Agreement negotiations initiated continued research collaboration into next generation Geared Turbofan
    - System analysis and design studies in 2009
    - 22" rig test at NASA Glenn 9'x15' wind tunnel in 2011
    - Powered nacelle integration test on half span model in Ames 11' in 2012



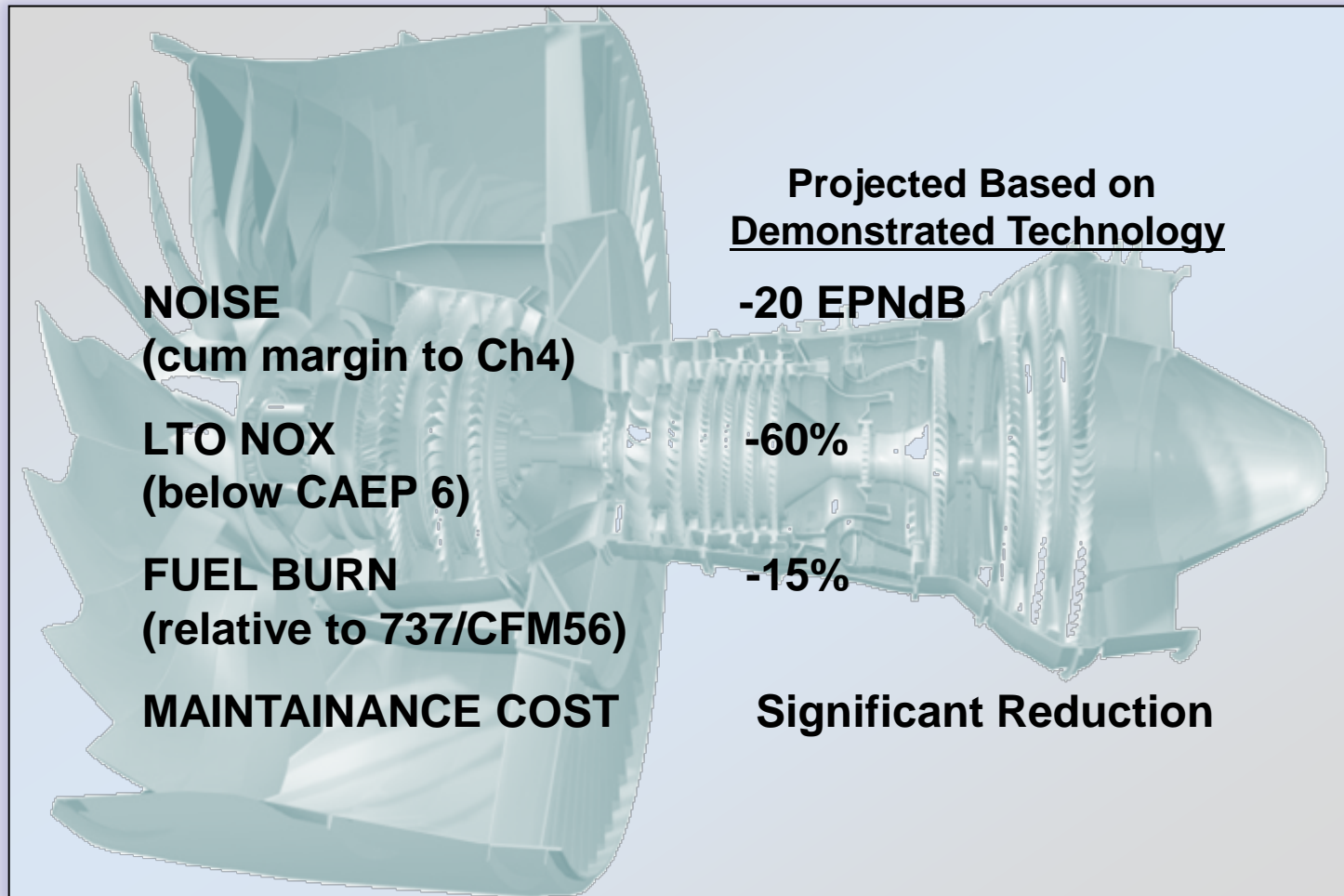
*GTDE Demonstrator Engine  
ground test*



# NASA / GE UHB Partnership Research

## Geared TurboFan (GTF™)

*Balanced Design Solution for Reduced Fuel Burn – Noise – Emissions*





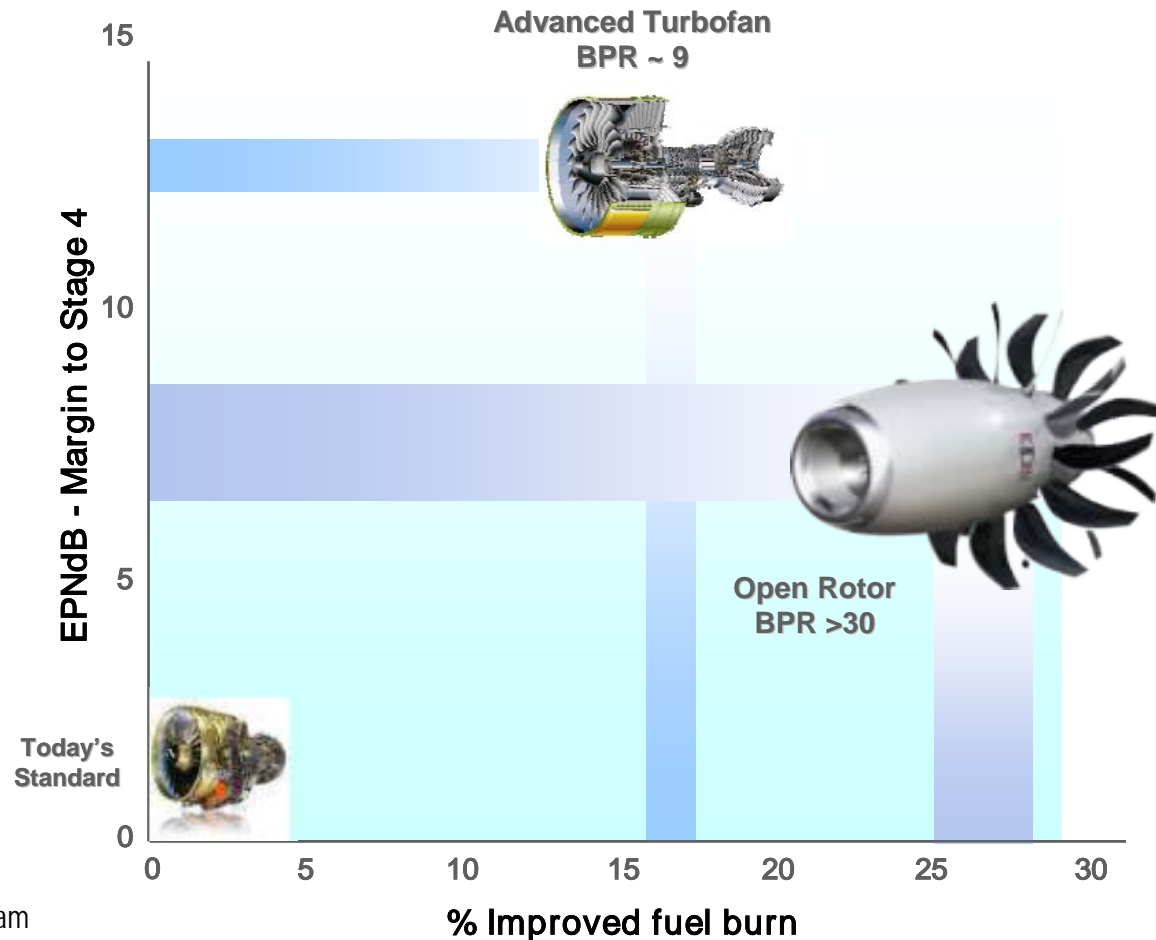
## NASA / GE UHB Partnership Research





# NASA / GE UHB Partnership Research

- *Meeting SFW Goals Requires Evaluating Game-Changing Architectures*
  - Open Rotor Technology has potential for significant performance improvement, but with noise goal challenges







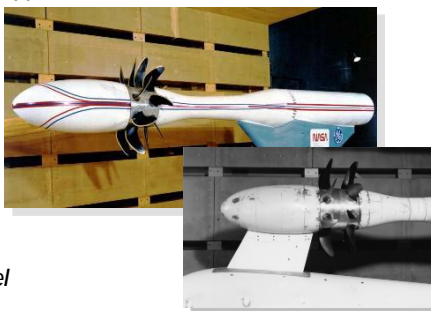
# NASA / GE UHB Partnership Research

## Leveraging the NASA / GE UDF® Experience and UHB Partnership



*Climb/Cruise in Glenn 8'x6' Wind Tunnel*

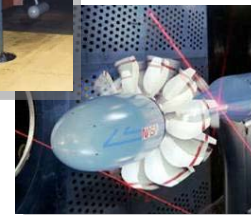
*Approach/Takeoff in Glenn 9'x15' Wind Tunnel*



*Installation Effects*

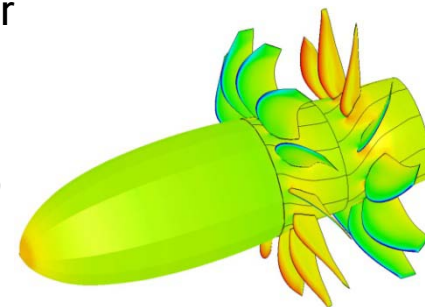


*Advanced Diagnostics*



*Counter-rotation Blade Profiles*

- Extensive 1980s collaborative testing experience of counter-rotation, open rotor concepts by NASA and GE, resulting in substantial experimental database to guide new activity
- Improved Computational Aeroacoustics developed by NASA/GE/Universities to evaluate new open rotor concepts
- Improved design and system analysis tools to screen potential candidates and minimize scale model test configurations
- Utilize proven NASA test facilities, improved diagnostic testing techniques and existing scale model test articles
- Build on GE expertise in composite construction and advanced core technology to achieve full Open Rotor potential



**GENx**



# NASA / GE UHB Partnership Research

## ➤ *General Electric Open Rotor*

- Space Act Agreement
  - Signed August 2008
  - Initiates collaborative research on Open Rotor propulsion concepts in NASA Glenn 9'x15' and 8'x6' wind tunnels in 3Q 2009

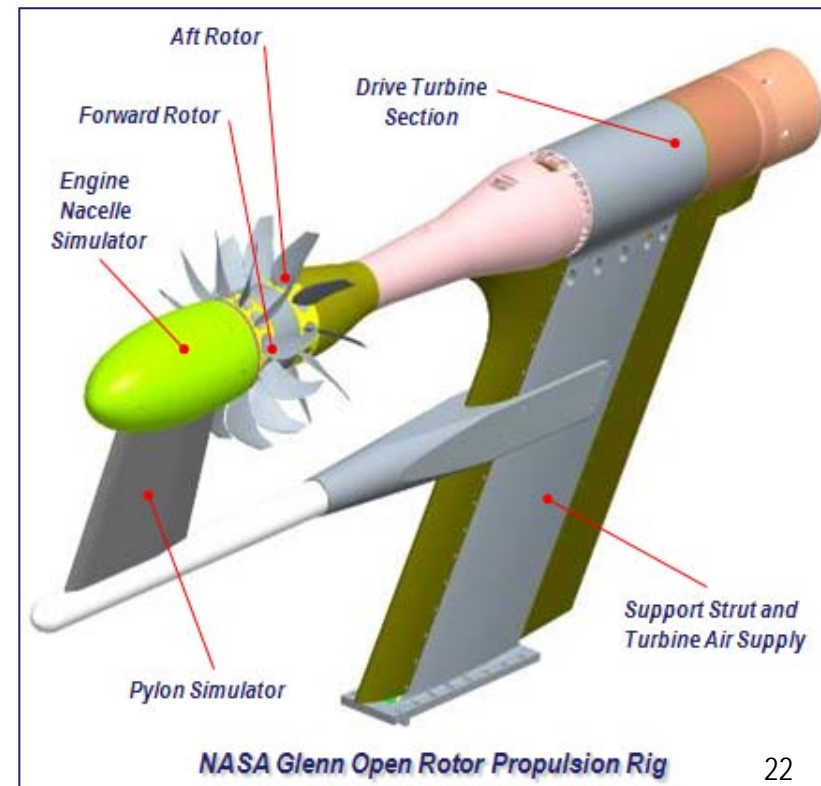
### ➤ *Test Objectives*

- Investigate performance and noise
- Produce shareable open rotor fan design
- Generate shareable database of test results

### ➤ *Plan*

- NASA refurbish and update 1980s counter-rotation propfan drive rig
- GE will design, fabricate and test 1980s technology based open rotor fan as Historical Baseline

GE Open Rotor Concept

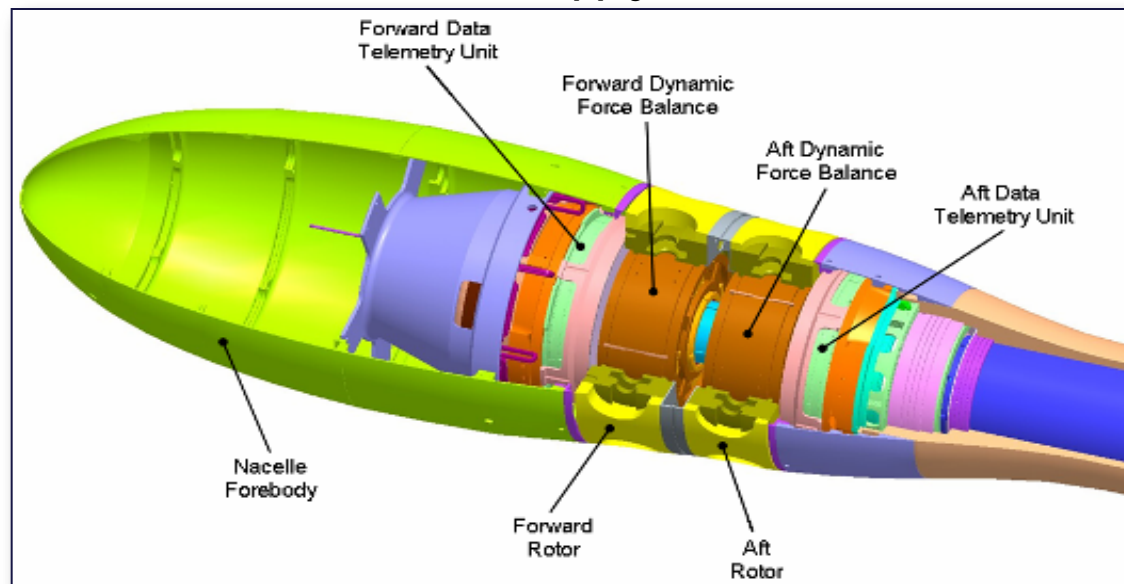




# NASA / GE UHB Partnership Research

## ➤ *NASA Glenn Open Rotor Propulsion Rig*

- Two independently controlled, counter-rotating shafts
- Each shaft capable of delivering up to 750 shp at maximum speed of 10,000 rpm
- Two-component rotating force balances measure up to 400 lbs thrust / 500 ft-lbs torque per rotor
- State-of-the-art digital telemetry units transmit data from each rotor to base system for transfer and storage on facility data system
- Up to 12 strain gages per rotor available for monitoring fan blade dynamics
- All subsystems (speed control, lubrication, air supply) are new, state-of-the-art designs







## ➤ *Future of Partnerships*

- *Though the challenges are big, exploiting partnerships and collaborative research opportunities can leverage their experience, expertise, facilities and resources to conduct research on Ultra High Bypass Propulsion concepts for the next generation of advanced aircraft designs, and investigate their viability as a new, game-changing aircraft propulsion technology in a changing, environmentally-conscious world*